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February 4, 2000
Subtask Order: HELEC3B1
Contract: NAS9-19100
MSAD-00-0156

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DRAFT

Advanced Life Support (ALS) Technologies List Version 2

SUMMARY: This list of potential ALS technologies is intended to be as comprehensive as possible so that it can be used to guide trade off studies that search for the best possible combination(s) of technologies for future missions. Here 'ALS technologies' is very broad, meaning any technology that has a significant interaction with the traditional life support functions of providing fresh air and water.

A major element of the ALS project is the BIO-Plex ground test bed, which will be used for integrated testing of many of these ALS technologies. In order to limit the cost of the BIO-Plex project, it is desirable to not construct the facility to accommodate an infinite array of test articles. As a result of a joint meeting between BIO-Plex representatives, SMAP and ALS Research and Technology Development (R&TD) representatives, a preliminary recommendation is made below with respect to which technologies should be specifically accommodated for during the BIO-Plex infrastructure development. These technologies are indicated below with a √√. Some technologies were deemed less desirable near term for BIO-Plex, primarily based on too high or low a TRL level, low likelihood of future development or limited applicability to the BIO-Plex facility. This does not mean that other technologies can never be added, just that they will not be specifically planned for at the present time. Technology evaluation efforts will continue and results will be reported to all elements of the ALS Program.

The mass, power and volume values listed are based on a crew of 6 and a mission duration of 400 days. The technologies on this list are as specific as possible and, in general, represent development efforts, which are currently ongoing. The list will be updated as additional information becomes available. Any missing values are yet to be determined (TBD) at this time. Please report any suggested additions or corrections for this draft to the author (281) 333-7384 or e-mail at bruce.duffield@lmco.com.

The definitions of TRL are as follows:

TRL 1 – Basic principles observed and reported
TRL 2 – Technology concept formulated

TRL 3 – Critical function proof-of-concept
TRL 4 – Component or breadboard validated in a laboratory
TRL 5 – Components validated in a relevant environment
TRL 6 – Prototype demonstrated in a relevant environment
TRL 7 – Prototype demonstrated in a space environment
TRL 8 – Design flight qualified
TRL 9 – System flight proven in mission operations

LIFE SUPPORT SUBSYSTEMS:

AIR

CO_2 Removal

- LiOH - Lithium hydroxide for CO2 removal without regeneration, high resupply rate.

$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
9	0	623	1.9
comment: ECLSS Analysis Tool v 2.0			

- √√ Molecular Sieve (4BMS) - In the 4BMS 2 synthetic zeolites beds are used alternately for absorption and desorption of CO_2 from the atmosphere in conjunction with 2 moisture removal beds.

TRL	POWER, W	MASS, kg	VOLUME, m^3
8	1000	255	1.55
comment: BVAD (values given are for 4BMS)			

- √√Molecular Sieve (2BMS) - The 2BMS uses a functional carbon molecular sieve and moisture removal beds are not needed.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Solid Amine Water Desorption (SAWD) - A steam heated solid amine (WA-21) is used instead of the zeolite bed in the 2BMS. Solid amine degrades with time requiring bed changeouts & moisture is released adding load to the Condensing Heat Exchanger. The SAWD doesn't require vacuum conditions like the 4BMS and 2BMS. The amine is no longer available.

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	570	55	0.04
comment: ECLSS Analysis Tool v 2.0			

- √√Solid Amine Vacuum Desorption (SAVD) (Water save CO_2) (new amine) Like the SAWD except uses vacuum to pull CO_2 and H_2O from the solid amine beds. If not venting to space vacuum, compressor development is required and TRL is lowered to the level of compressor development.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	122	80	0.15
comment: ECLSS Analysis Tool v 2.0			

- Solid Amine Vacuum Desorption (SAVD) (RCRS amine with no water saver) (old amine) Like the SAWD except uses vacuum to pull CO_2 and H_2O from the solid amine beds

TRL	POWER, W	MASS, kg	VOLUME, m^3
9	122	80	0.15
comment: ECLSS Analysis Tool v 2.0			

- Electrochemical Depolarization Concentrator (EDC) - Combines CO_2 with H_2 & O_2 (fire or explosion risk). EDC is a net power generator.

$$CO_2 + \tfrac{1}{2}O_2 + H_2 \longrightarrow CO_2 + H_2O + Elec.energy + Q_{heat}$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	44	42	0.06
comment: ECLSS Analysis Tool v 2.0			

- √√Air Polarized Concentrator (APC) - Like the EDC but doesn't require H_2, *i.e.* safer but is a net power consumer.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	285	42	0.06
comment: ECLSS Analysis Tool v 2.0			

- Electroactive carriers within membranes - Fixed within membranes capable of binding CO_2 in the reduced state and releasing CO_2 in the oxidized state. Low TRL.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Membrane Removal - To date has shown inadequate selectivity for CO_2.
- √√Green Plants - Photosynthetic conversion of CO_2 to O_2. See BPS technologies for more details.

TRL for gas conversion (wheat in JSC Phase III test)
5

- Algal Systems - Photosynthetic conversion of CO_2 to O_2.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: TRL given for US or Japanese technology; Russian technology TRL 5			

- √√Enzyme facilitated CO_2 capture - Seen at the ALS poster session at the Center for Advanced Space Studies March 1999, work of Dr. Michael Tractenberg, (see Sandra Brasseaux for details).

TRL	MASS, kg	POWER, W	VOLUME, m³
3			

- √√CO_2 compressor

TRL	MASS, kg	POWER, W	VOLUME, m³
3			

CO_2 Reduction

- √√Sabatier - produces water and methane. Uses high temp. (450 - 800 K)

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m³
6	130	31	0.01
comment: Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98./ Vol. - ECLSS Analysis Tool v 2.0			

- √√Bosch - produces Carbon and water. Uses high temp. (700 - 1000 K)

$$CO_2 + H_2 \longrightarrow C + 2H_2O + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m³
4	242	68	0.09
comment: ECLSS Analysis Tool v 2.0			

- √√ACRS - a Sabatier, g/l separator and Carbon Formation Reactor (CFR), CFR packs carbon better than Bosch but uses operating temp of 1100 K.
Sabatier Rx with methane conversion to carbon.

$$CH_4 \longrightarrow C + 2H_2$$

TRL	POWER, W	MASS, kg	VOLUME, m³
3	400	180	0.30
comment: NASA/ARC In House Life Support Review Databook.			

- √√CO_2 Electrolysis (zirconia system)- Under development for ISRU. Reduces CO_2 & produces O_2 but operates at high temp (1100 K) and low TRL.

$$CO_2 + H_2O \longrightarrow CO + H_2O + H_2$$

$$CO \longrightarrow C + CO_2$$

TRL	POWER, W	MASS, kg	VOLUME, m³
4			
comment:			

- √√ Green Plants - Photosynthetic conversion of CO_2 to O_2. See BPS technologies for more details.

TRL for gas conversion (wheat in JSC Phase III test)
5

- Algal Systems - Photosynthetic conversion of CO_2 to O_2.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: TRL given for US or Japanese technology; Russian technology TRL 5			

- Microchannel CO2 Reduction

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

O_2 Generation & Delivery

- √√Solid Polymer Water Electrolysis (SPWE) - Uses solid polymer electrolyte to produce O_2 from water.

Electrolysis Rx.

$$2H_2O + Energy \longrightarrow 2H_2 + O_2 + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
7	1021	64	0.05
comment: ECLSS Analysis Tool v 2.0			

- Static Feed Water Electrolysis (SFWE) - Uses aqueous electrolyte to produce O_2 from water.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	959	54	0.03
comment:			

- √√CO_2 Electrolysis - Reduces CO_2 & produces O_2 but operates at high temp (1100 K). (see above in CO_2 reduction)

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- √√Green Plants - Photosynthetic conversion of CO_2 to O_2. (see above in CO_2 reduction)

- Algal Systems - Photosynthetic conversion of CO_2 to O_2. (see above in CO_2 reduction)

- Artificial Gill - Binds O_2 from low concentration streams by combining O_2 with organometallic compounds like hemoglobin. Could be used to recover O_2 from plant chambers or the Martian atmosphere.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- √√O_2 Concentrator (COTS)

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

Diluent Gas Supply

- √√Gas storage - high pressure liquid or gaseous N_2

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment: ECLSS Analysis Tool v 2.0			

- Thermal Catalytic Dissociation of hydrazine or ammonia to N_2

$$3N_2H_2 \longrightarrow N_2 + 4NH_3 + heat$$

$$4NH_3 + heat \longrightarrow 2N_2 + 6H_2$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
2-9?			
comment:			

- √√Argon Recovery Bed –

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

Trace Contaminant Control System (TCCS)

- √√Activated Charcoal Adsorption

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- √√Photo catalyst oxidation

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- √√ISS Baseline TCCS

TRL	POWER, W	MASS, kg	VOLUME, m^3
6	244	83	0.25
comment: ECLSS Analysis Tool v 2.0			

- √√Improved TCCS (see John Graf) - features a regenerable sorbent bed that is regenerated using space vacuum

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	128	77	0.13
comment: BVAD			

- √√Regenerable Air Purification System (RAPS) - (NASA (ARC) & Vanderbilt U. joint effort) use of a humidity-swing desorption cycle, which uses less power than a thermal desorption cycle and requires no venting of air and water to space vacuum.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Biological Air Filter - Contains a liquid phase, containing microbes, separated by the gas phase (air) by membranes.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- √√Soil Reactor Beds (SRB) - Air movement through living soil that supports a population of plants.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Air Quality Monitoring
  1. √√Rice Sniffer
  2. √√E-nose

	TRL
1	5
2	

BIOMASS

- Lighting
  - Direct Lighting
    1. √√High Pressure Sodium
    2. √√Light Emitting Diodes (LED)
    3. Fluorescent – issue with scaling up
    4. √√Microwaves - potential power saver
    5. Solar Space Greenhouse

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	6			
2	7			
3	4			
4	5			
5	2			
comment:				

  - Indirect Lighting
    1. Fiber Optic
    2. √√Light Pipe

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	4			
2	4			
comment:				

  - Heat Removal Systems for Lighting
    1. √√Water Jacketed High Pressure Sodium
    2. √√Cold Plate
    3. √√Air Heat Exchangers
    4. Barriers
       a. √√Teflon
       b. √√Tempered glass
       c. √√Lexan
       d. Water

	TRL
1	4
2	6
3	6
4a	4
4b	5
4c	4
4d	4

- Nutrient/Water Delivery
    1. √√Solid Media
    2. √√Hydroponics
    3. Aeroponics

	TRL
1	4
2	5
3	4

- Nutrient Composition Management
    1. √√On demand
        a. Conductivity
        b. Ion Specific
    2. √√Model Based

	TRL
1a	5
1b	3
2	4

- Nutrient Sources
    1. √√Pure chemicals
    2. Resource recovery
        a. √√BSAB/Compost
        b. √√Incineration
        c. √√Waste water recovery

	TRL
1	5
2a	4
2b	3
2c	2

- Specialized Harvest & planting equipment
    1. √√Tray Lid Conveyor
    2. √√Tray Lift
    3. √√Processing Conveyor
    4. √√Tray Lid
        a. Support Frame
        b. Rooting Matrix
    5. √√Automated Seeder
    6. √√Harvester
    7. √√Germination cabinet
    8. √√Crop dryer

	TRL
1	4
2	4
3	4
4a	4
4b	4
5	2
6	2
7	3
8	2

- √√Plant Health Monitors TRL(4)
- √√Higher productivity crops. TRL(2)
- √√Shorter crops. TRL(2)

FOOD

1. √√Extruder - uses shear force, > temperature and > pressure to convert plant material into edible food ingredients. Increases available food texture and variety. Current models have high power usage, produce high degree of waste, are heavy and require high crew time.
2. √√Grain/Flour Mill - convert various food crops to flour. Current models are noisy & heavy.
3. √√Soy Milk Machine - Needed for processing soybeans to milk, tofu (used as meat substitute) etc. Current models are difficult to clean.
4. √√Food processor
5. √√Bread machine
6. √√Dishwasher
7. √√Refrigerator
8. √√Freezer (active & passive)
9. √√Dehydrator
10. √√Press (oil extraction hydraulic)
11. √√Pasta press
12. √√Automatic tofu/milk (ProSoya)

13. √√Galley
    a. Specialty faucet
    b. Triple compartment sink
14. √√Stovetop
15. √√Toaster oven
16. √√Mixer
17. √√Convection Oven
18. √√Bagel Maker
19. √√Blender

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1				
2				
3				
4	4			
5	5			
6	3			
7	3			
8	3			
9				
10				
11				
12				
13	a-3, b-3			
14	3			
15	4			
16	4			
17	4			
18	4			
19	4			
comments:				

THERMAL

Heat Acquisition

- √√Aluminum Coldplates

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- √√Condensing HX's

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- √√Avionics air HX's

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Adsorbent/desiccant H2O removal
  1. √√solid
  2. √√liquid

	TRL
1	6
2	4

- √√Cold plate shelf - integrate with structures, metal or composite, possible incorporation of heat pipes

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- √√Carbon velvet heat exchanger

TRL	POWER, W	MASS, kg	VOLUME, m^3
3-5?			
comment:			

- Fault tolerant heat exchangers

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Thermal storage – note: expand technologies list to include specific technologies
- √√Cooling jacket

TRL	POWER, W	MASS, kg	VOLUME, m^3
2-3			
comment:			

Heat Transport

- √√Single-phase pumped loop

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Low-power two-phase pumped loop

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Vapor compression heat pump
    1. √√Solar powered
    2. √√Conventional

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	3			
2	6			
comment:				

- √√Internal heat pump - for low temperature loads

TRL	POWER, W	MASS, kg	VOLUME, m^3
6			
comment:			

- √√Thermal-powered heat pump

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Fluids that can be used inside and outside the spacecraft (single phase)
    1. √√Water
    2. √√Freon

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	9			
2	3			
comment:				

Heat Rejection

- Aluminum radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Flexible fabric radiators - metal or carbon

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Laminate radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Laminate loop heat pipe

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Composite radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Mars convection device

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Parabolic radiator shade

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Radiator surface cleaning and refreshing

TRL	POWER, W	MASS, kg	VOLUME, m^3
1			
comment:			

- Water membrane evaporator (WME)

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- New Sublimator

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

WASTE

- Store waste

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- P/C fullup

1. √√Super Critical Water Oxidation (SCWO) - No catalyst needed. Can reuse most of the heat generated. Produces potable water from all input waste waters. Operates 647 K & 2.21 x 10^7 Pa.

2. √√Wet Oxidation - High temp & pressure oxidation of wet slurries. Output depends on the temperature and pressure used. Particularly attractive in conjunction with plants as CO_2 is produced.
3. √√Combustion/Incineration - Requires evaporation prior to combustion. Highly oxidized waste products. Highly inefficient.
4. Electrochemical Oxidation - Non- thermal (oxidizes with catalytic electrodes) and doesn't use atmospheric O_2. Less power requirements than SCWO, Wet Oxidation or Combustion/Incineration.
5. IRAD -

- Partial Biological Digestion/Composting
  6. √√composting
  7. √√Continuous Stirred Tank Reactor (CSTR) - could be used to recover nutrients for plants.
- Partial P/C
  8. √√Carbonization - heat to 250 °C & 10342 kPa (1500 psi) then cool – liquid phase process
     - recover water.
     - for deactivation after biological processes

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	4-5	1440	694	2.12
2	4			
3	4-5	388	72.6	0.57
4	3			
5				
6	4			
7	4-5			
8				
comment: 1. NASA/ARC In House Life Support Review Databook. 3. NASA/ARC In House Life Support Review Databook.				

- √√Sterilize & Stabilize - This is the only method that does not require O_2 and would be most appropriate for partly open food systems.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- √√Pyrolysis (TRL 3) – gas phase process
- √√Freeze Dry (TRL 4)
- √√Dehydrate (TRL 4)
- √√Steam reforming (TRL 3)
- √√Trash compactor
- √√Garbage disposal

WATER

ISS Baseline Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
6	990 VCD only - 65	1269 + 2108(expendable) VCD only - 48	VCD only - 0.08
comment: All three tech.'s included; Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98; VCD only ECLSS Analysis Tool v 2.0			

- Vapor Compression Distillation (VCD) - 96% recovery of water from urine with low energy use. Rotating parts may cause high failure rate. Can have problems with recondensing of volatile organics and ammonia.

TRL
6

- Multifiltration (MF) - Polishing apparatus; high expendables

TRL
6

- Volatile Removal Assembly (VRA) - removes low molecular weight organics using catalytic oxidation.

TRL
7

Alternate ISS Baseline Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	TIMES only - 183	TIMES only - 56	TIMES only - 0.11
comment: TIMES only; ECLSS Analysis Tool v 2.0			

- Thermoelectric Integrated Membrane Evaporation System (TIMES) - Uses hollow fiber membrane technology, that can be unreliable. 95% water recovery. Can have problems with recondensing of volatile organics and ammonia.

TRL
4

- Multifiltration (MF) - Polishing apparatus; high expendables

TRL
6

- Improved Post Processor - pre-oxidizer plus adsorbent.

TRL
4

√√Advanced Node 3 Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	1270	211 + 145(expendable)	
comment: Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98			

- Bioreactor - TOC and Nitrogen oxidation using cultures of mixed microbes.
  - Packed Bed Biological Water Processor (PBWP) - anerobic packed bed reactor

TRL
5

  - Nitrification Biological Water Processor (NBWP) - aerobic membrane reactor - O_2 delivery via membrane for nitrification

TRL
4

  - Membrane Biological Water Processor (MBWP) - aerobic membrane reactor - O_2 delivery via membrane for TOC reduction.

TRL
4

  - Biological Water Processor: (trickling filter bioreactor) - aerobic reactor without O_2 delivery via membrane

TRL
4

  - Biological Water Processor: (immobilized cell bioreactor) - aerobic reactor without O_2 delivery via membrane

TRL
5

  - Magnetically separated BWP

TRL
3

  - Membrane / CSTR combo

TRL
2

- Microfiltration or Ultrafiltration

TRL
5

- Reverse Osmosis (RO) - Low energy use and low expendables, Produce s brine requiring additional treatment.

TRL
5

- Air Evaporation System (AES) - Used in Advanced Node 3 Architecture as a RO brine processor but could also be used as a urine processor. Uses evaporation via a wick + condensation.

TRL
5

- Advanced Post Processor - TOC and organic salts polishing by adsorption and ion exchange beds in conjunction with photolysis or photocatalysis.

TRL
4

Alternative Technologies

- √√Vapor Phase Catalytic Ammonia Removal (VPCAR) - high temperature vaporization & catalytic oxidation of volatile impurities *i.e.* doesn't need pretreatment or post treatment. Uses hollow fiber membrane technology, that can be unreliable, and high operating temperatures.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	100	68	0.24
comment: NASA/ARC In House Life Support Review Databook.			

- Super Critical Wet Oxidation (SCWO) - Waste treatment above 647 K and 2.21 x 10^7 Pa. Complete oxidation of organics and precipitation of most inorganics.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3 (WRS) or 4(ARC)?	1440	694	2.12
comment: NASA/ARC In House Life Support Review Databook.			

- Aqueous Phase Catalytic Oxidation Post-treatment System (APCOS) - Polishing apparatus that uses catalytic oxidation.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4 (WRS) or 5(Duff & Lin)?			
comment:			

- Electrodialysis - Uses ion exchange resins and membranes to deionize water.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3 (WRS) or 4(ARC)?	460	759	0.261
comment: NASA/ARC In House Life Support Review Databook.			

- √√Green Plants - Photosynthetic conversion of CO_2 to O_2 (See BPS section for details)

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment: TRL for water recovery			

- √√Water Recovery from Condensate - Recovered from transpiration of plants (includes gray water recovery from plants) or evaporated from breathing, skin surfaces or other sources.

TRL
2 (WRS) or 5(Duff & Lin)?

- Many other kinds of bioreactor e.g. destruction of organics such as soap in the NDS of a hydroponics system by the microbes in the root mat, continuously stirred tank reactors, etc. Composter might be able to treat heavily contaminated water e.g. urine better than other types.

- √√Photocatalysis - comsumable free post-processing[2g]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Freeze purification by lyopholization (lower latent heat than distillation processes) [2g]

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Other types of still, e.g. using solar energy directly or thermopervaporation. (The latter may be related to TIMES.) [2g]

TRL
1

- Other electrochemical approaches involving ozone or hydroxyl ions generated in situ to destroy organics. [2g]

TRL
2-3

- √√Disinfection / Sterilization Technologies
    - Microbial check valve

TRL
9

- Filters

TRL
9

- Peroxide

TRL
2-3

- Phase Separation
  - √√Passive membranes

TRL
4-5

  - Vortex

TRL
6

  - Powered

TRL
9

OTHER:

- Magnetic Gas Liquid Separator - Boeing Corp. technology in testing stage. Seen at the ALS poster session at the Center for Advanced Space Studies March 1999.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Multistage Vacuum Rotary Distiller (MVRD)

EXTERNAL LIFE SUPPORT INTERFACES:

HUMAN ACCOMODATIONS

- √√Washer & dryer

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- √√Disposable & permanent clothing

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- √√Vacuum shower (TRL 9)

INTEGRATED CONTROL

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